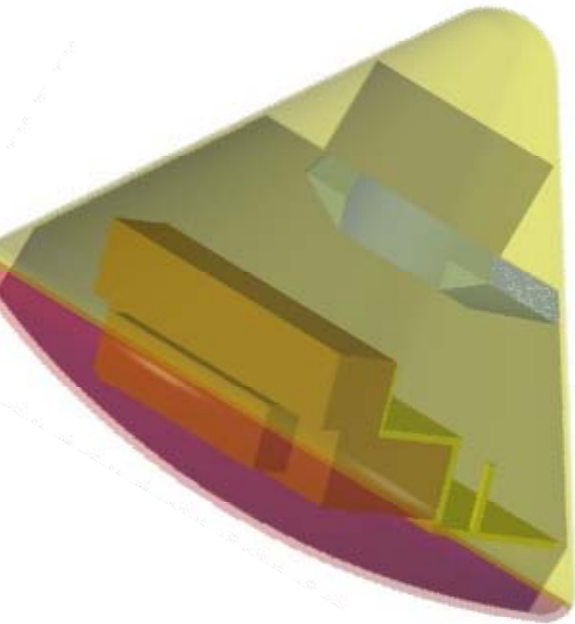


# System Architecture Tools and Assumptions

Jeremy Shidner  
Paige D. Thomas

*Contributions made by:*  
*Dean Bucher*  
*David Reeves*  
*Carlos Roithmayr*  
*Michael Scher*



# Aerospace Architecture Tools

- Mass Sizing Tool – Developed ‘In-House’
- SPSP – Space Propulsion Sizing Program
- APAS – Aerodynamic Preliminary Analysis System
- POST – Program to Optimize Simulated Trajectories
- TOPSIS - Technique for Order Preference by Similarity to Ideal Solution
- AHP – Analytical Hierarchy Process
- ❖ *Tools used to develop a human lunar architecture*



# Lunar Architecture Project Summary

- Followed NASA Spiral 3 requirements
- Analyzed Apollo mass, technology, cost, and reliability
- Revised mission architecture
- Updated Apollo for new requirements and technologies
- Analyzed mass, cost, and reliability



# Reference Tool: Historical Data

- Data collected from 1950-1970's lunar exploration endeavors
- Used as reference points for new tools verification (ex. NAFCOM, SPSP)
- Provides spring board for new testing
- Provided baseline and valuable reference data points for this project



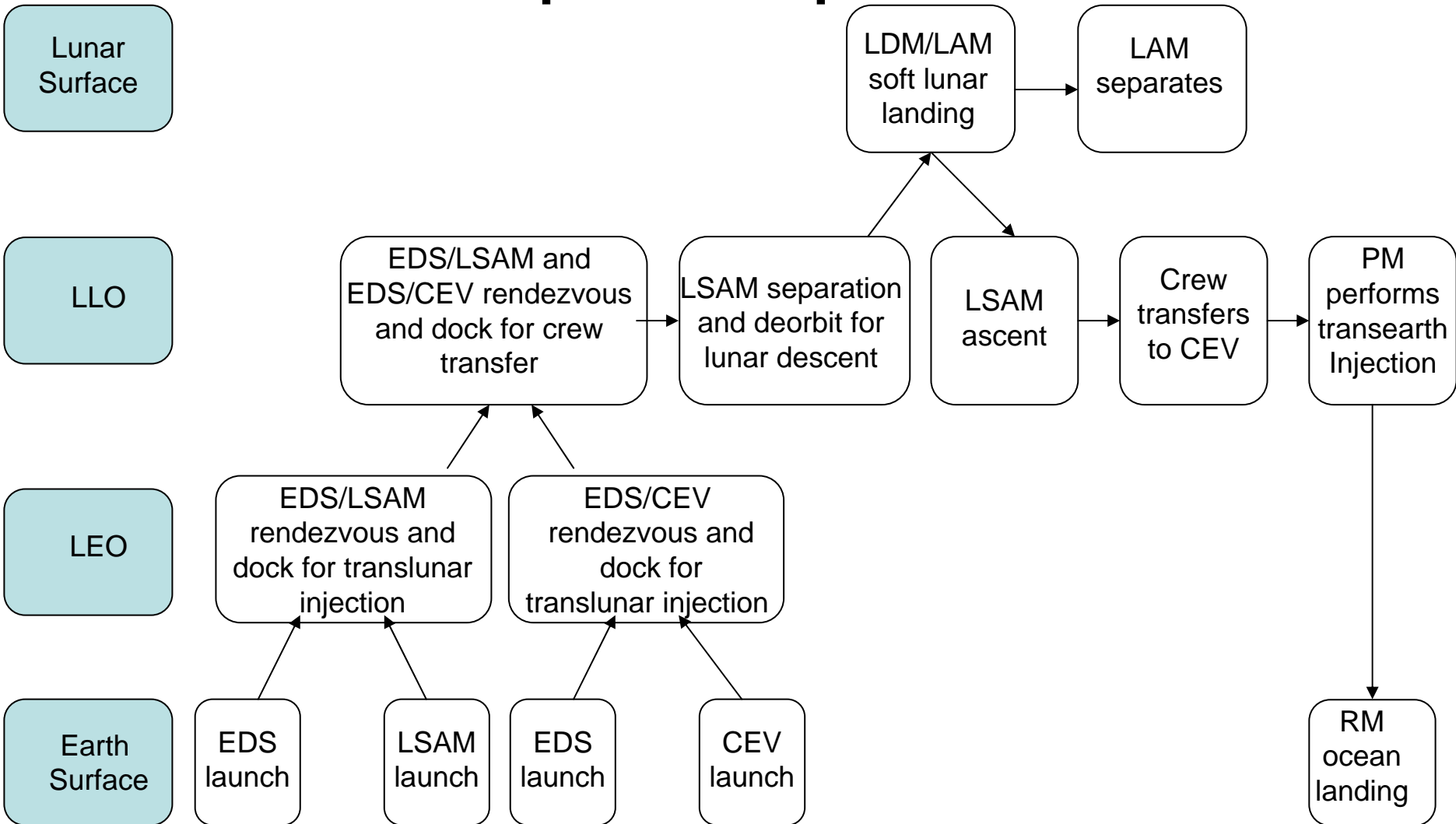
# Lunar Architecture Requirements

Requirements	CSM	CEV	
Crew	3	4	
Diameter	3.9116	4.4958	m
Total $\Delta V$	1951	2588	m/s
Propellant Surplus	5%	10%	
Cargo	138	500	kg
EVA's	0	2	
Uncrewed Days	0	70	days
Crewed Days	14	11.5	days
	LEM	LSAM	
Crew	2	4	
Crew Days	4	7	days
Landing $\Delta V$	4010	4385	m/s
Return Cargo	0	250	kg



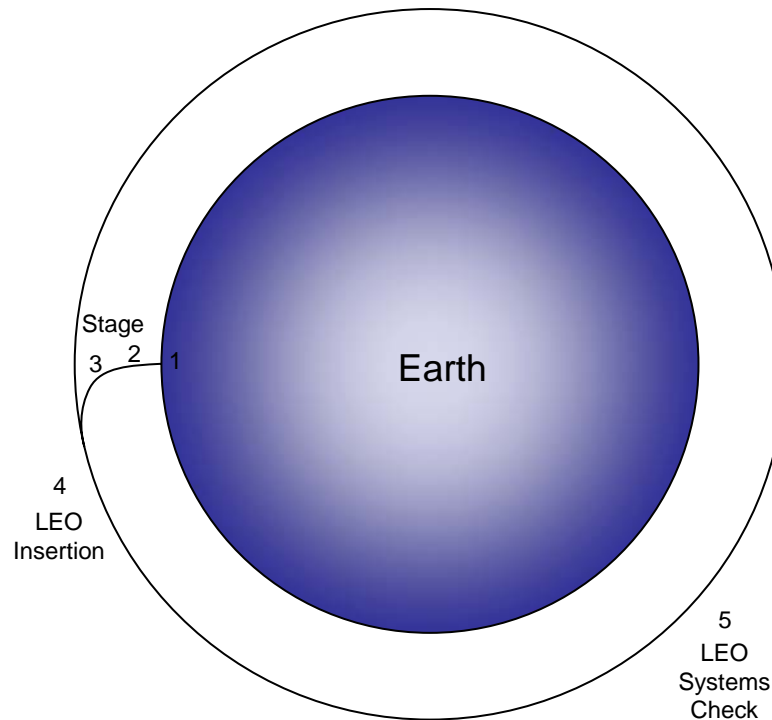
# Lunar Architecture

## Concept of Operations



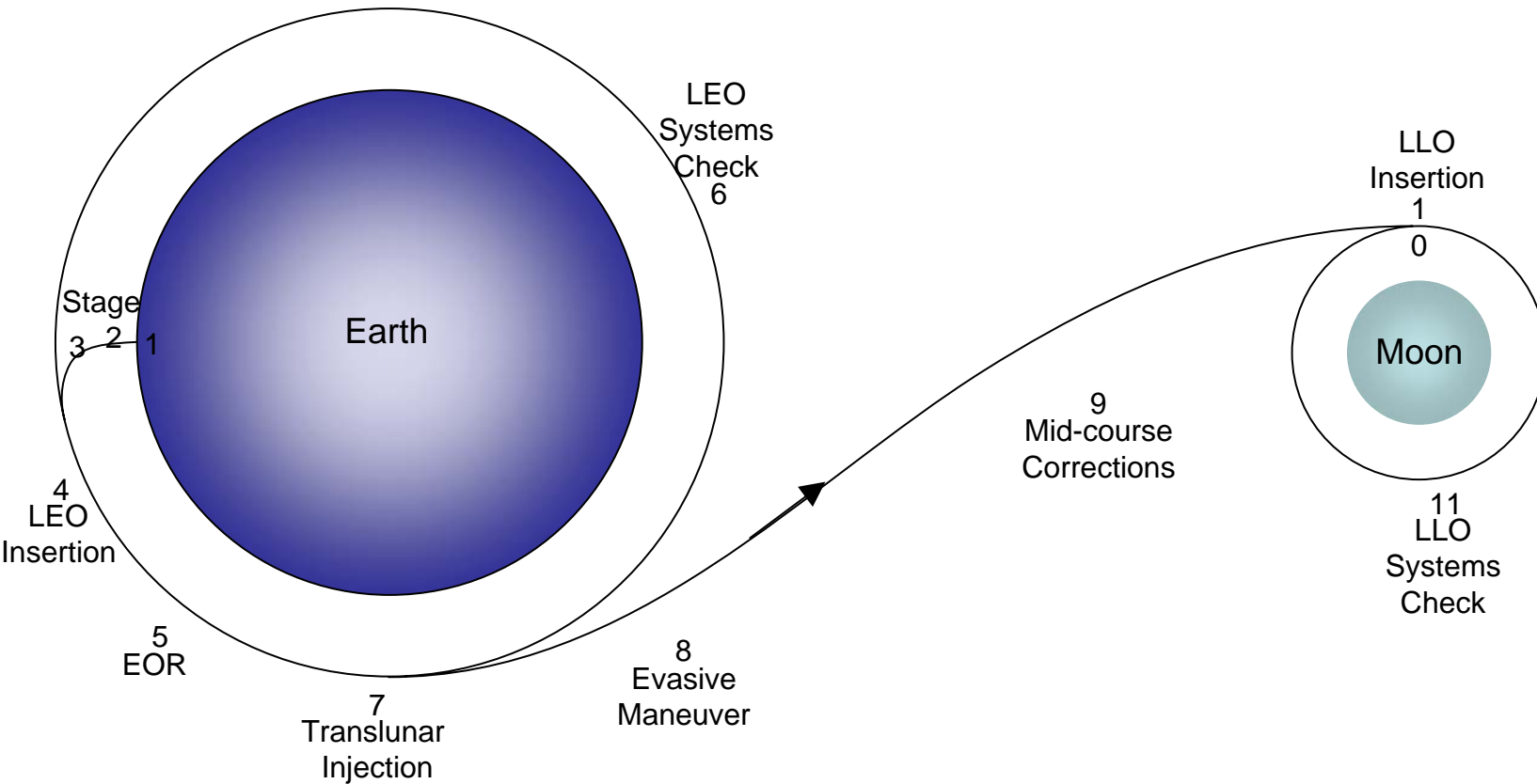
# Lunar Architecture

## Launch 1 – Unmanned Carrying LSAM EDS



# Lunar Architecture

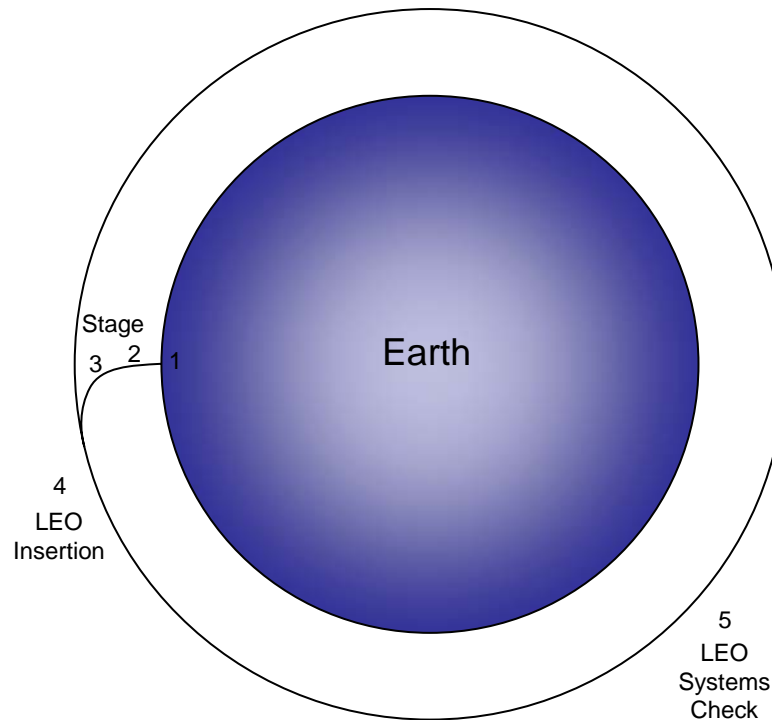
## Launch 2 – Unmanned Carrying LSAM





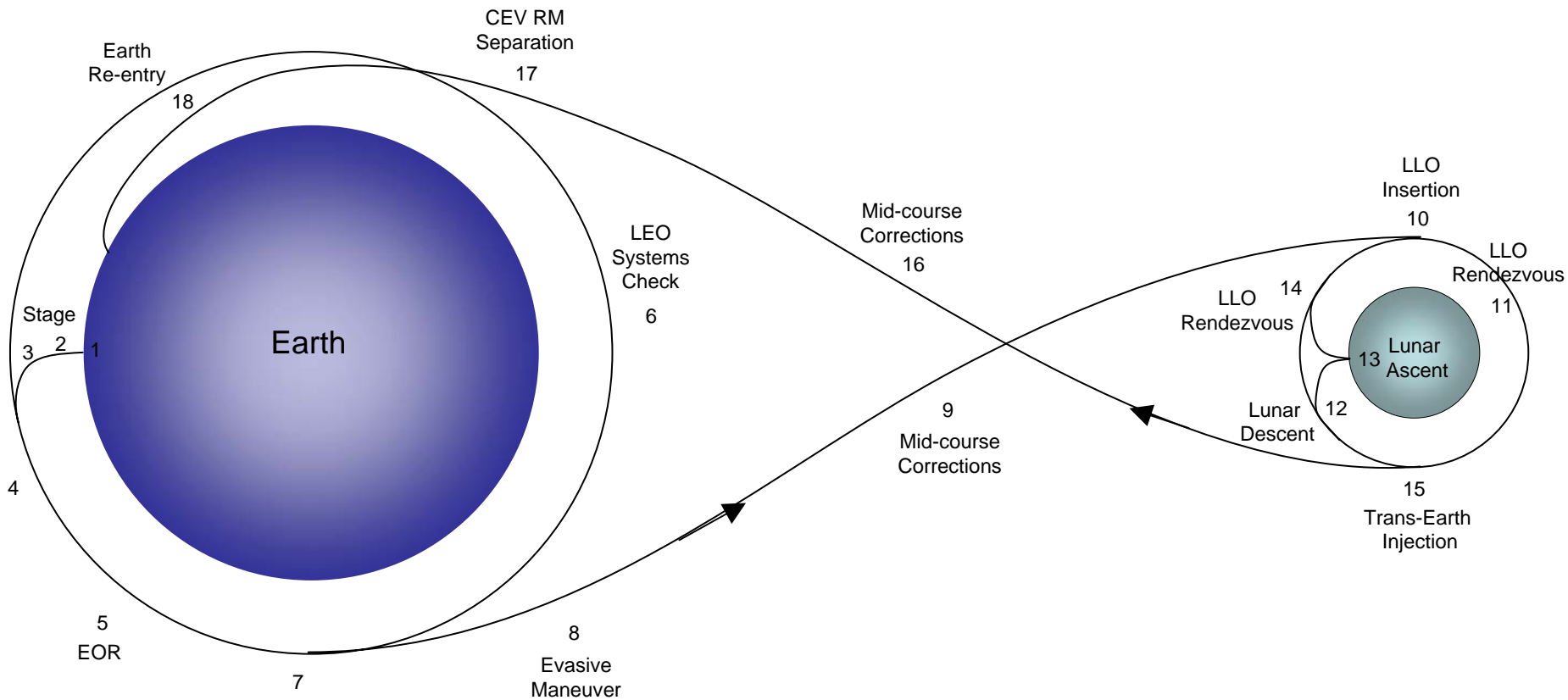
# Lunar Architecture

## Launch 3 – Unmanned Carrying CEV EDS



# Lunar Architecture

## Launch 4 – Manned Carrying CEV



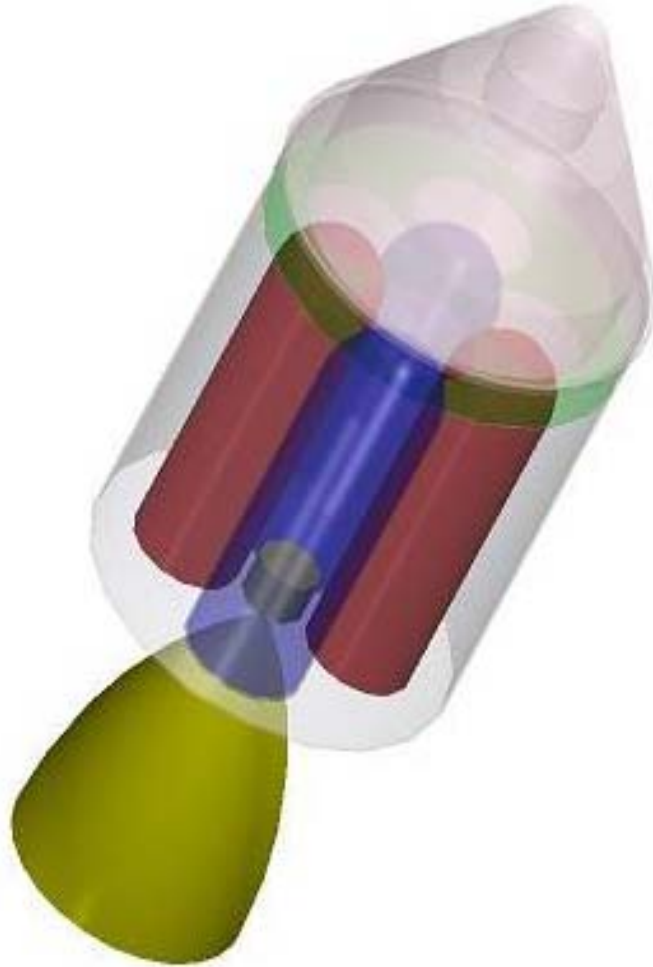
# CAD Tool: Solid Edge

- Computer Aided Design creates models with ease.
- User-defined equations allow Solid Edge to accept a minimum number of inputs and build the model up from that point.
- Easy to use rendering and animator allows the user to more accurately convey the shapes and roles the architecture will play.



# Original Apollo

(via Solid Edge)

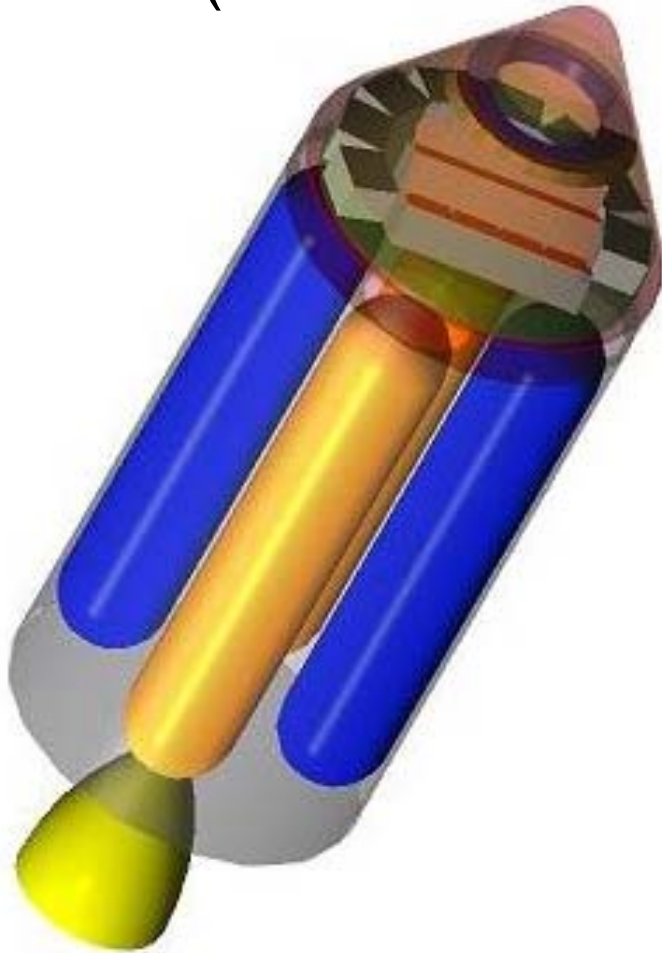


- Sized using original mass and geometry data
- Basis for sizing subsequent designs



# Apollo Technology with New Requirements

(via mass sizing tool and Solid Edge)



- Sized up from original Apollo with new requirements
- Assumes no advancements in technology
- Note: CAD tool allows engineer to more intuitively understand change in size.



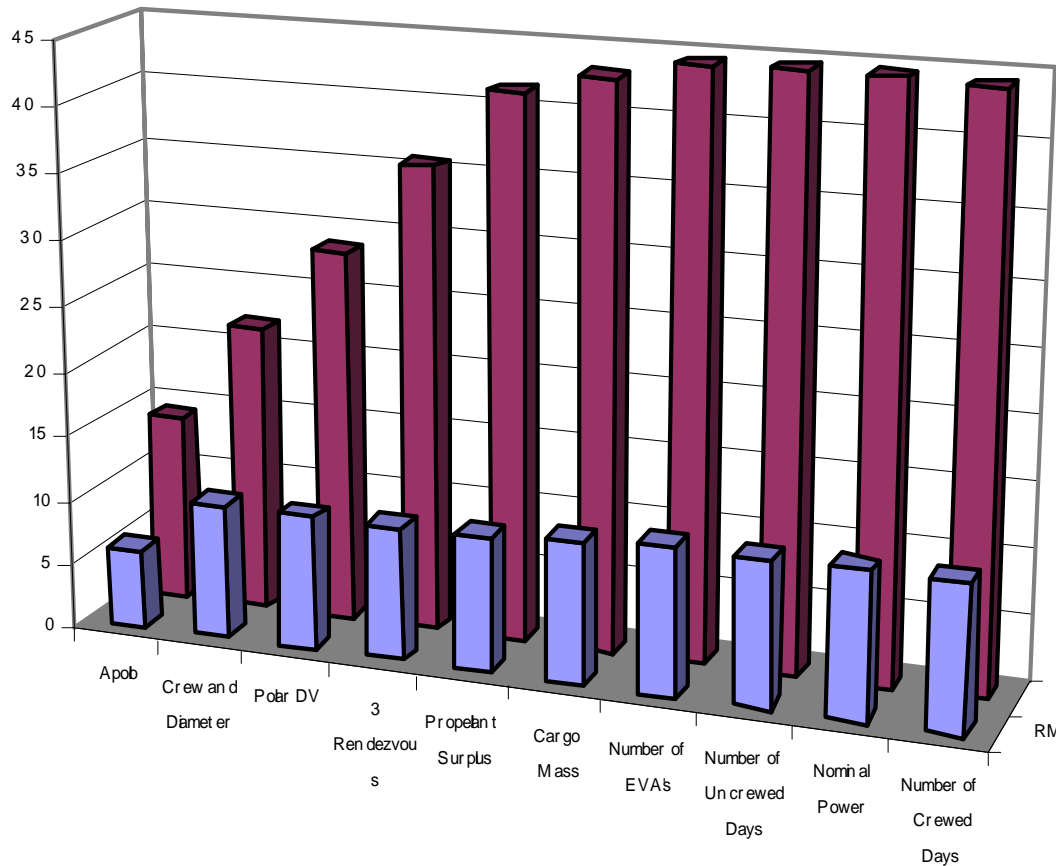
# SPSP

- Excel based program which performs mass sizing and geometric sizing
- Provides 2-D drawing outputs in Excel as well as 3-D Pro-Engineer drawing outputs
- Provides sizing for overall systems as well as individual subsystems like propulsion, power, reaction control, and structure subsystems



# Sizing Apollo CSM with New Requirements

(via mass sizing tool)

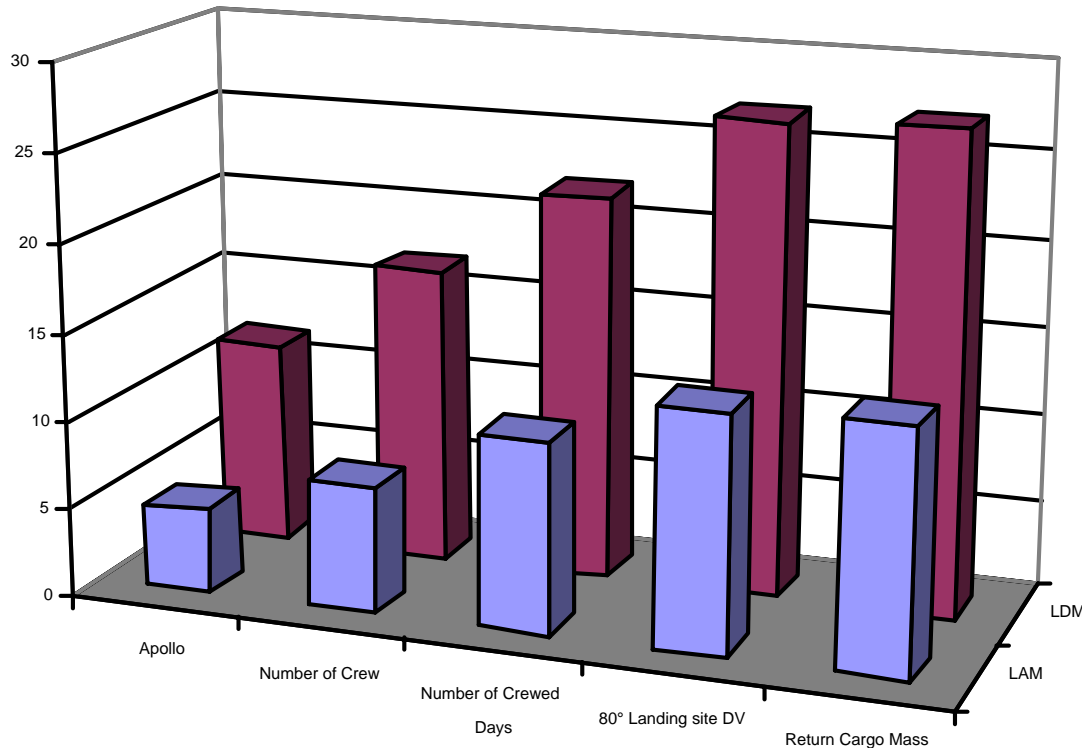


- Apollo Service Module mass tripled
- Apollo Command Module mass doubled
- Crew size and Delta V most significant



# Sizing Apollo LM with New Requirements

(via mass sizing tool)



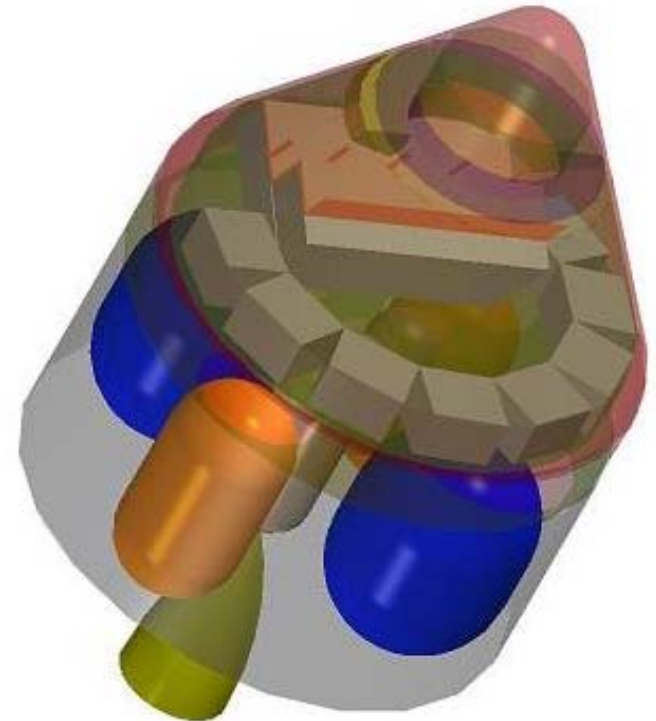
- Lunar Descent Module more than doubled
- Lunar Ascent Module nearly tripled
- Number of crewed days most significant for Lunar Ascent Module
- Each requirement adds about 5 MT to Lunar Descent Module





# Project Baseline

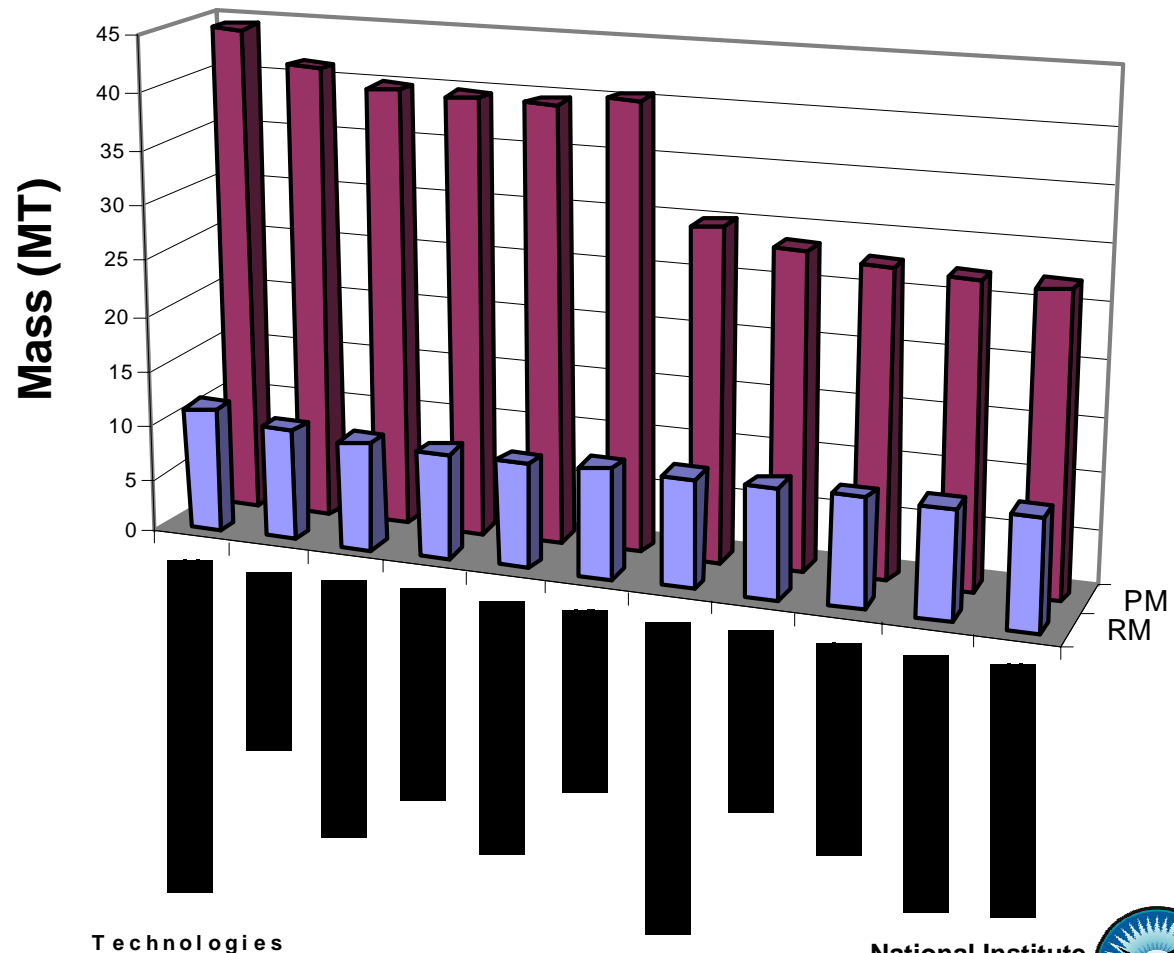
- Updated technology on to Apollo with new requirements
- Primary driver in size: number of crew
- Uses LOX/Kerosene main engine and RCS on Propulsion Module
- Re-entry Module is 5.87m with Aluminum primary structure
- Switch to hydrazine RCS for Re-entry Module and Lunar Ascent Module
- Use of storable propellant engines on Lunar Surface Access Module (LSAM) with higher  $I_{sp}$  than Apollo Lunar Excursion Module
- Shuttle-type fuel cells and Li-ion batteries
- Inflatable airlock



# Sizing Apollo CSM with New Requirements and New Technologies

(via mass sizing tool, SPSP, and historical data)

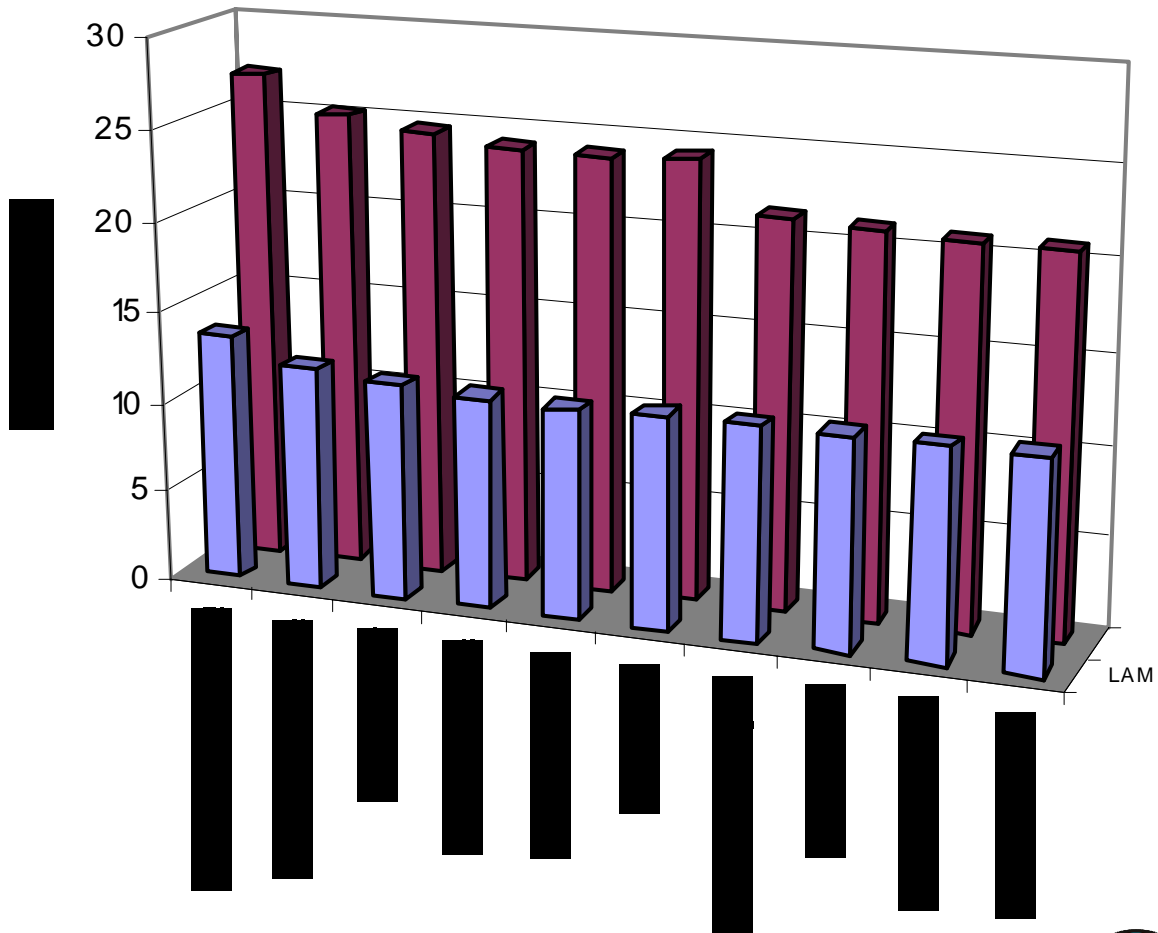
- Re-entry Module changed most by TPS technology
- Propulsion Module changed most by main engine technology



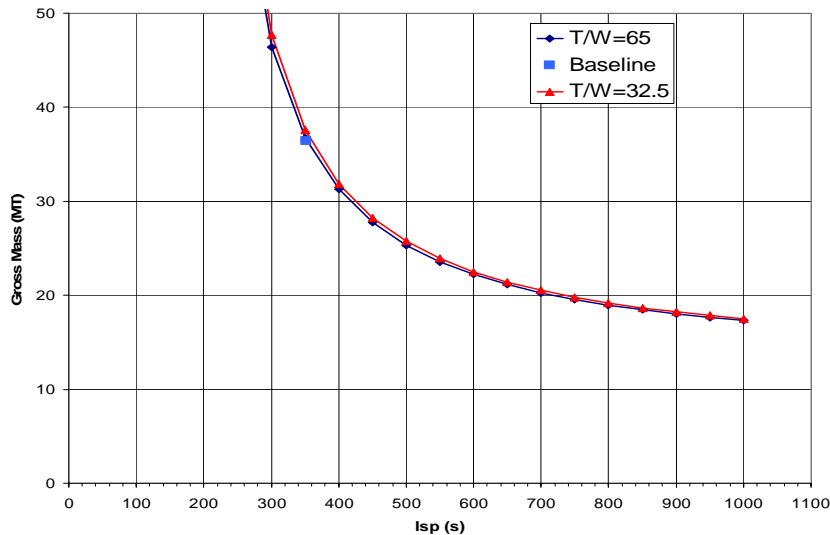
# Sizing Apollo LM with New Requirements and New Technologies

(via mass sizing tool, SPSP, and historical data)

- Assumes Lunar Descent Module and Lunar Ascent Module use identical engines
- Better engines result in largest mass savings

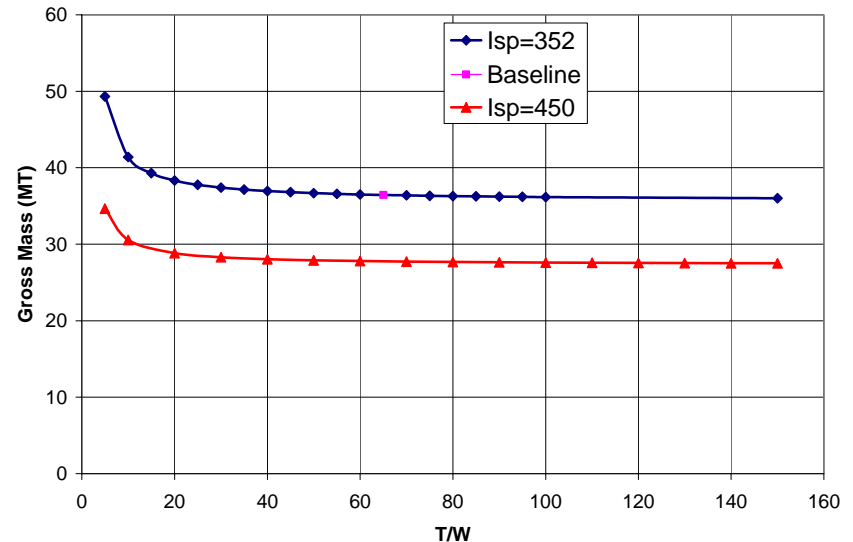


# Engines Trade Study (via SPSP)



## T/W

- Overlap because T/W is not a significant factor of gross mass
- T/W of at least 20 to reach flat part of curves

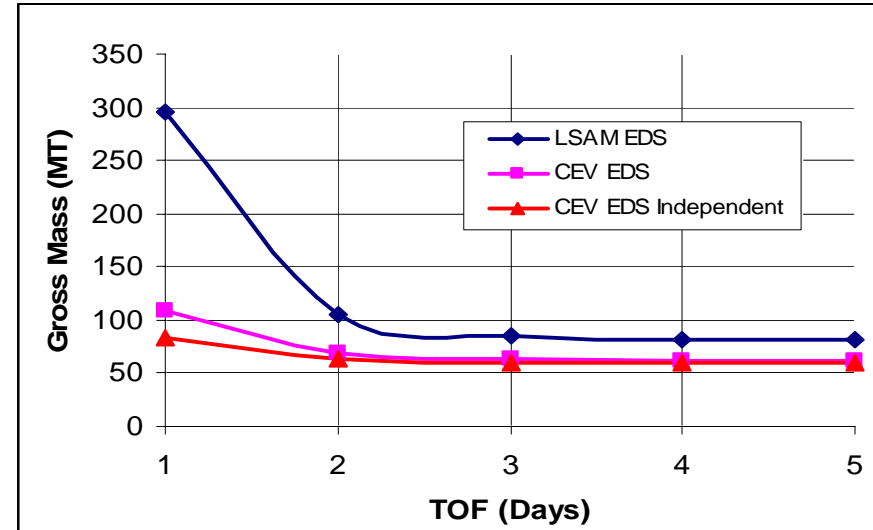
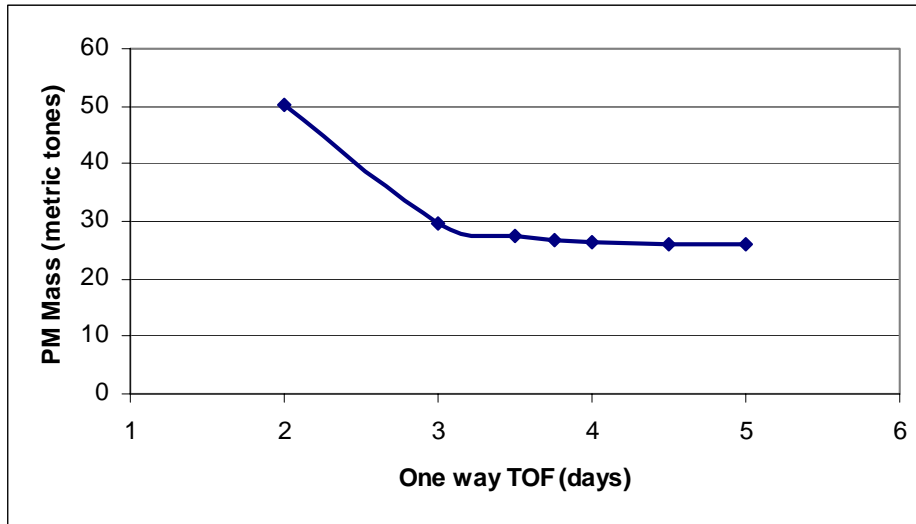


## Isp

- Decrease Isp shifts T/W curve down
- Demonstrates small Isp change causes large mass change
- Largest chemical  $I_{sp} \sim 460$  s



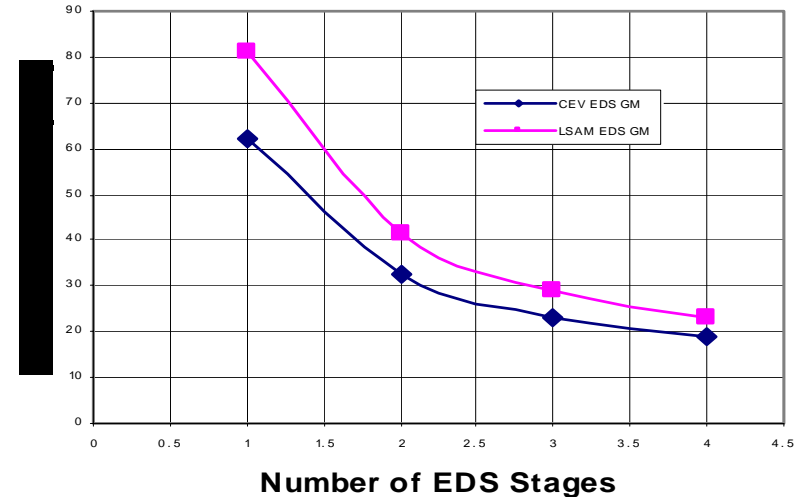
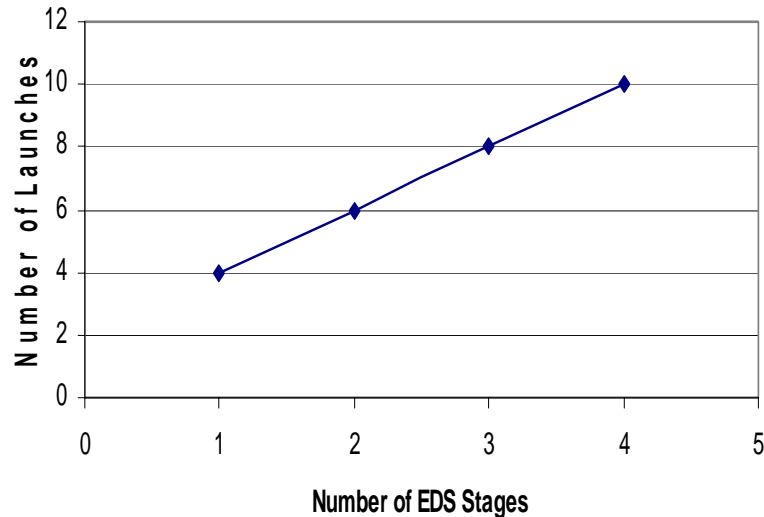
# Time of Flight (TOF) Trade Study (via mass sizing tool)



- CEV EDS same as LSAM EDS, but has less propellant
- CEV EDS independent is different from LSAM EDS
- Longer TOF yields lower gross mass from propulsion viewpoint, but adds to ECLSS on CEV
- 4 days on inhabited CEV, 5 days on uninhabited LSAM



# Number of Earth Departure Stages Trade Study (via SPSP)



- Both EDS's are the same, but CEV EDS has less propellant
- Increase number of stages to accommodate lower capability launcher
- Lower payload launcher causes drastic increase in number of launches



# Power Trade Study

(via SPSP)

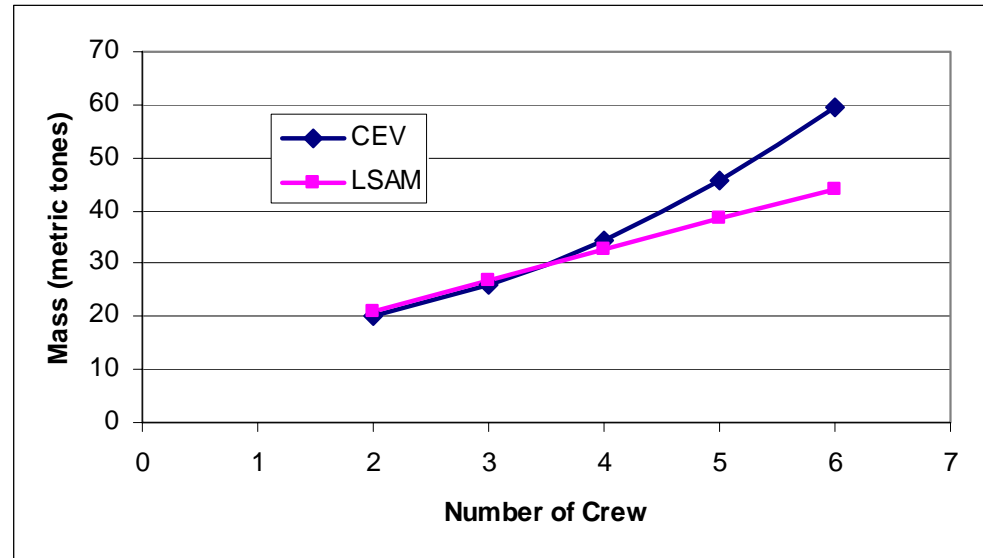
- CEV & LSAM need 7 kW (Prime power) and 1 kW (back up power)
- Ga-Ar body mounted solar arrays and Lithium-Ion batteries are the lightest
- 3 Lithium-Ion batteries included on the Re-entry Module for the reentry portion of the mission



# Crew Size Trade Study

(via mass sizing tool)

- Adding a fourth crew member is the most influential requirement change from Apollo.
- The CEV is slightly heavier than the LSAM with the required crew of four which is beneficial for the EDS arrangement.
- After 4 crew, the CEV grows much faster than the LSAM, mainly due to the simplicity of the LSAM design.



# of Crew	CSM	LSAM
3	25.92	27.03
4	34.41	32.78
% Change	32.75%	21.27%





# Earth Re-entry Trajectory

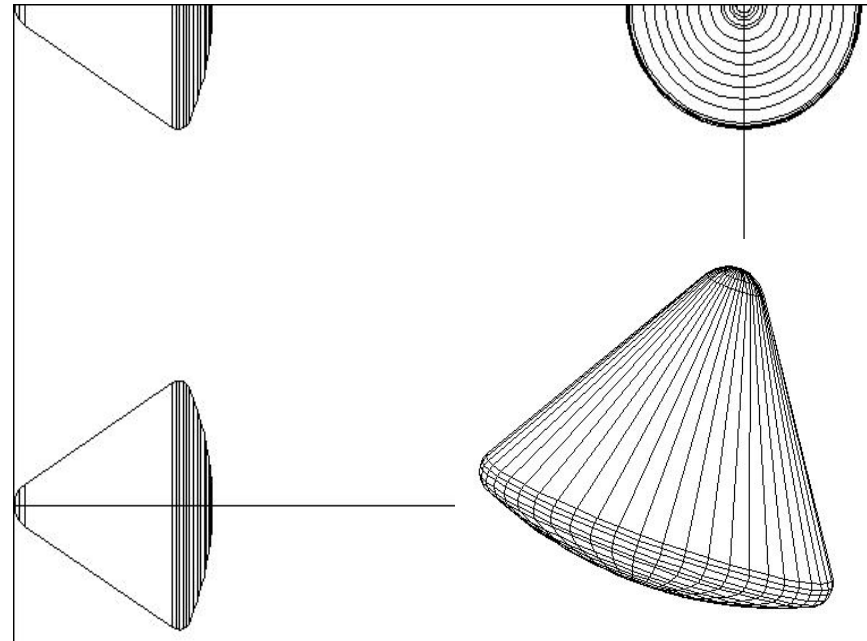
- APAS
  - Aerodynamic Preliminary Assessment System
  - Aerodynamic coefficients
- POST
  - Program to Optimize Simulated Trajectories
  - Create nominal trajectory simulation for Apollo CM. CM re-enters under trimmed flight conditions using bank angle profile from NASA flight data.
  - Perform simulations for baseline RM and final revision RM flying under same conditions as Apollo CM.



# APAS

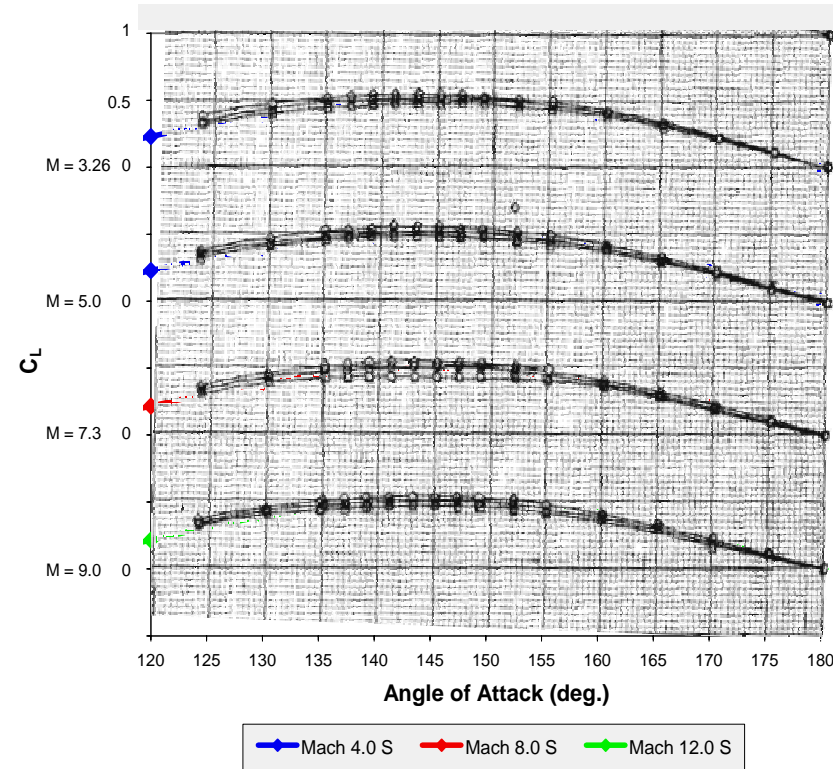
(Aerodynamic Preliminary Analysis System)

- Uses hypersonic analysis based on non-interfering, constant pressure, finite element analysis
- Design is broken down into panels and analyzed
- Viscous, Base, and Impact Drag is taken into account



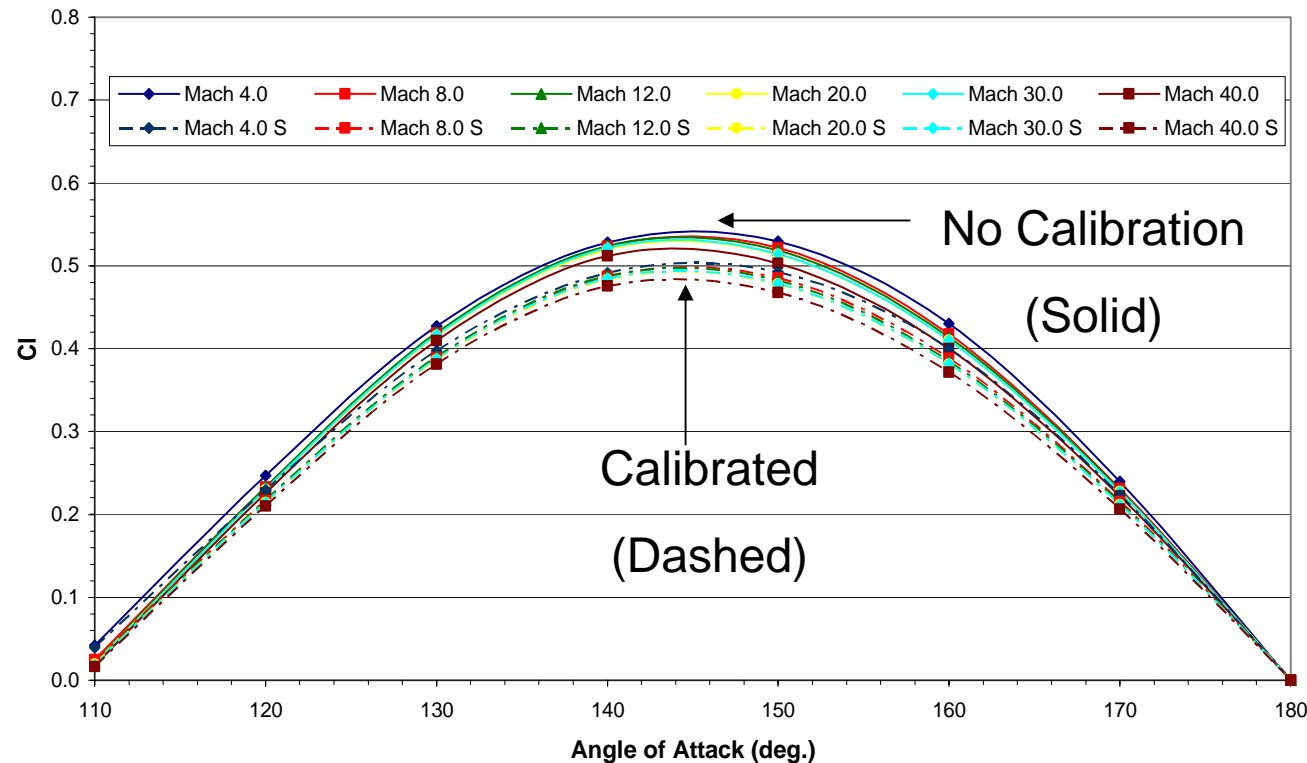
# APAS Theory Validation

- Results were validated according to old Apollo aerodynamic characteristics



# APAS Calibration

- A calibration of APAS results had to be made in order to fly the RM at a nominal trajectory



# POST

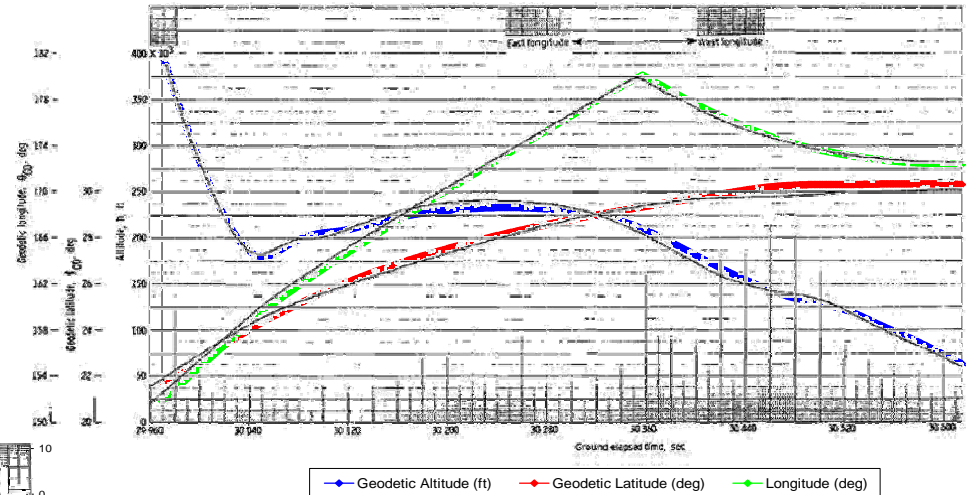
- Generalized point mass, discrete parameter targeting and optimization program.
- Generalized planet and vehicle models.
- Uses generalized routines, inputs, and outputs to provide the capability to model numerous different types of designs.
- Difficult to use, but very beneficial.



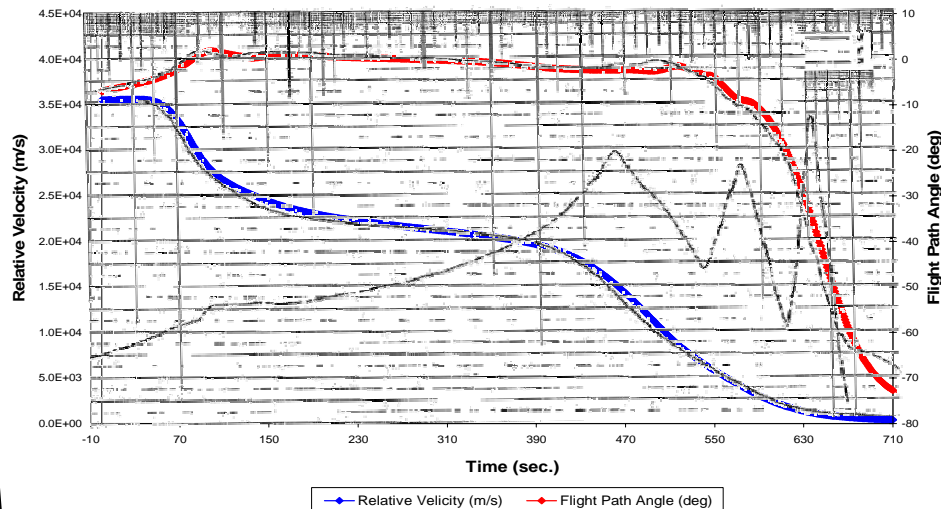
# Apollo Reconstruction Using POST

- Apollo 4 CM Entry Simulation

- Geodetic Altitude, Latitude, And Longitude

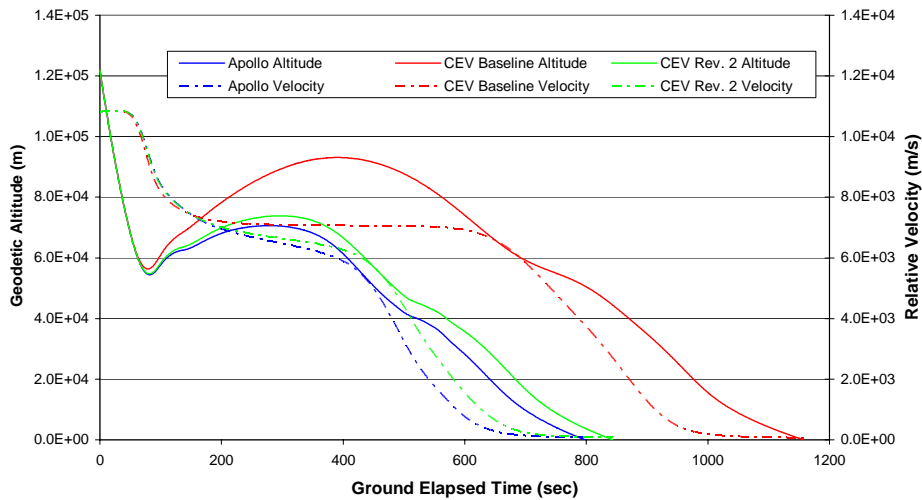


- Relative Velocity and Flight Path Angle



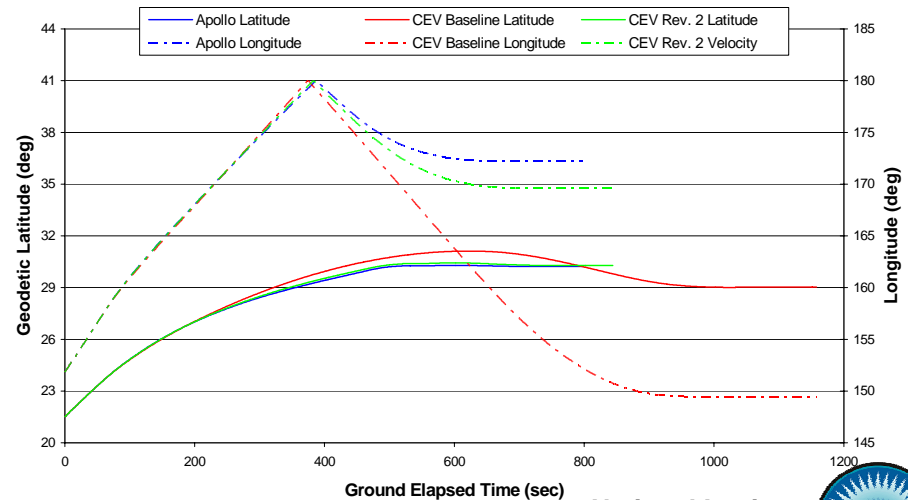
# RM Trajectory

- Re-entry Module Simulation



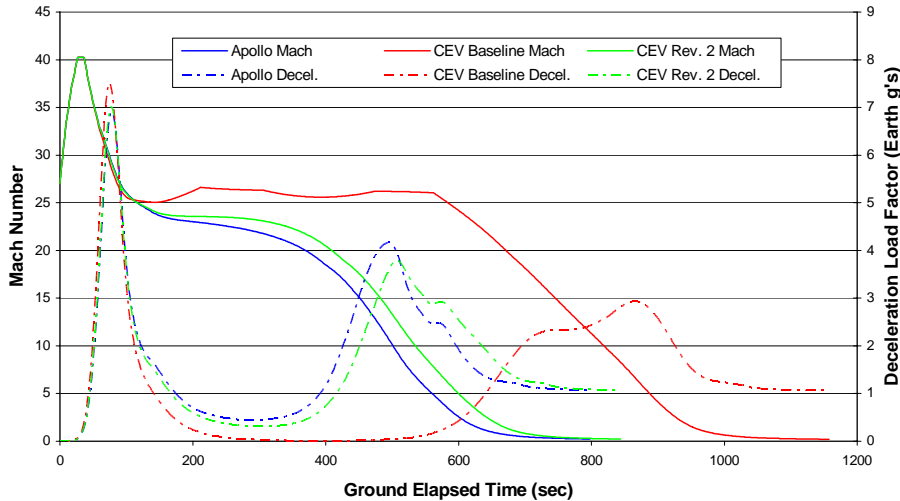
- Geodetic Altitude and Relative Velocity

- Geodetic Latitude and Longitude



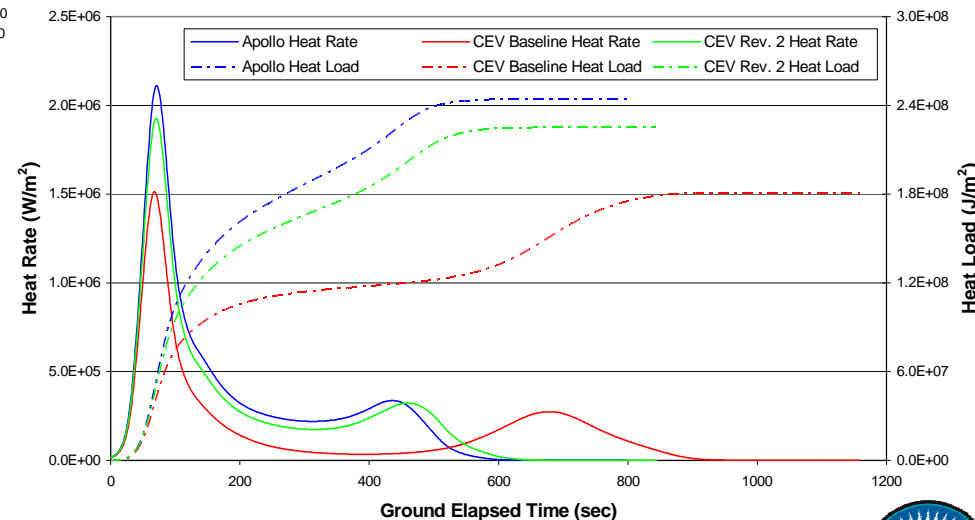
# RM Trajectory

- Re-entry Module Simulation



- Mach Number and Deceleration Load Factor

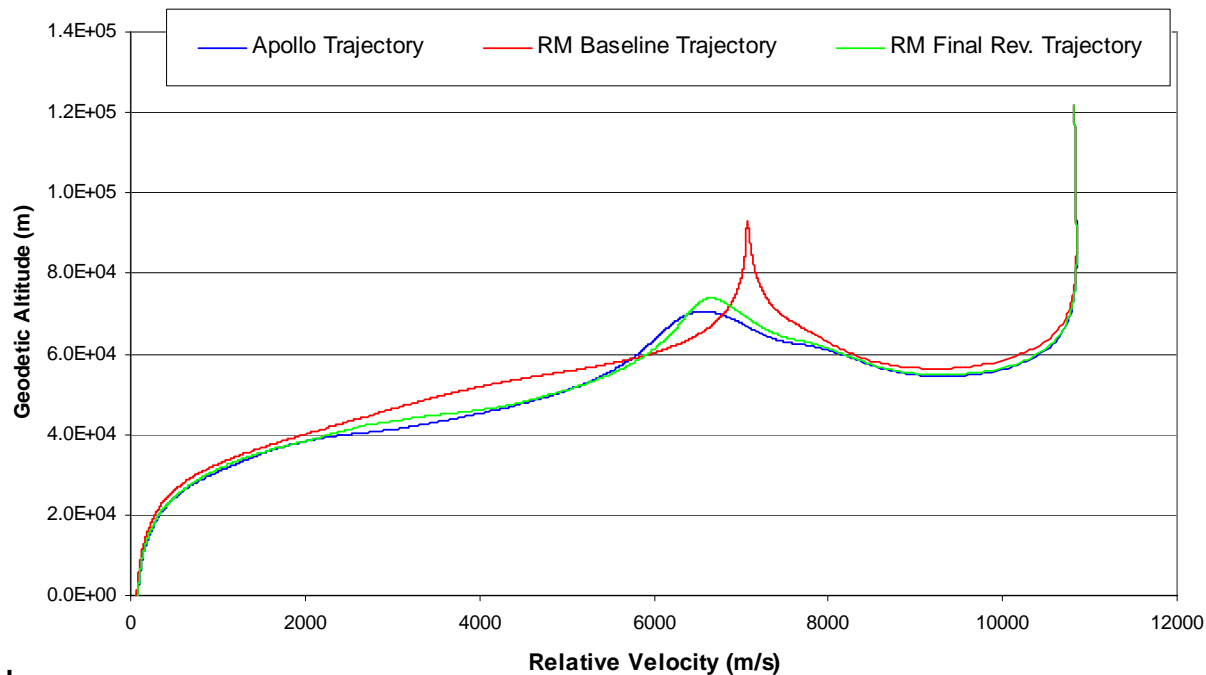
- Convective Stagnation Point Heat Rate and Heat Load



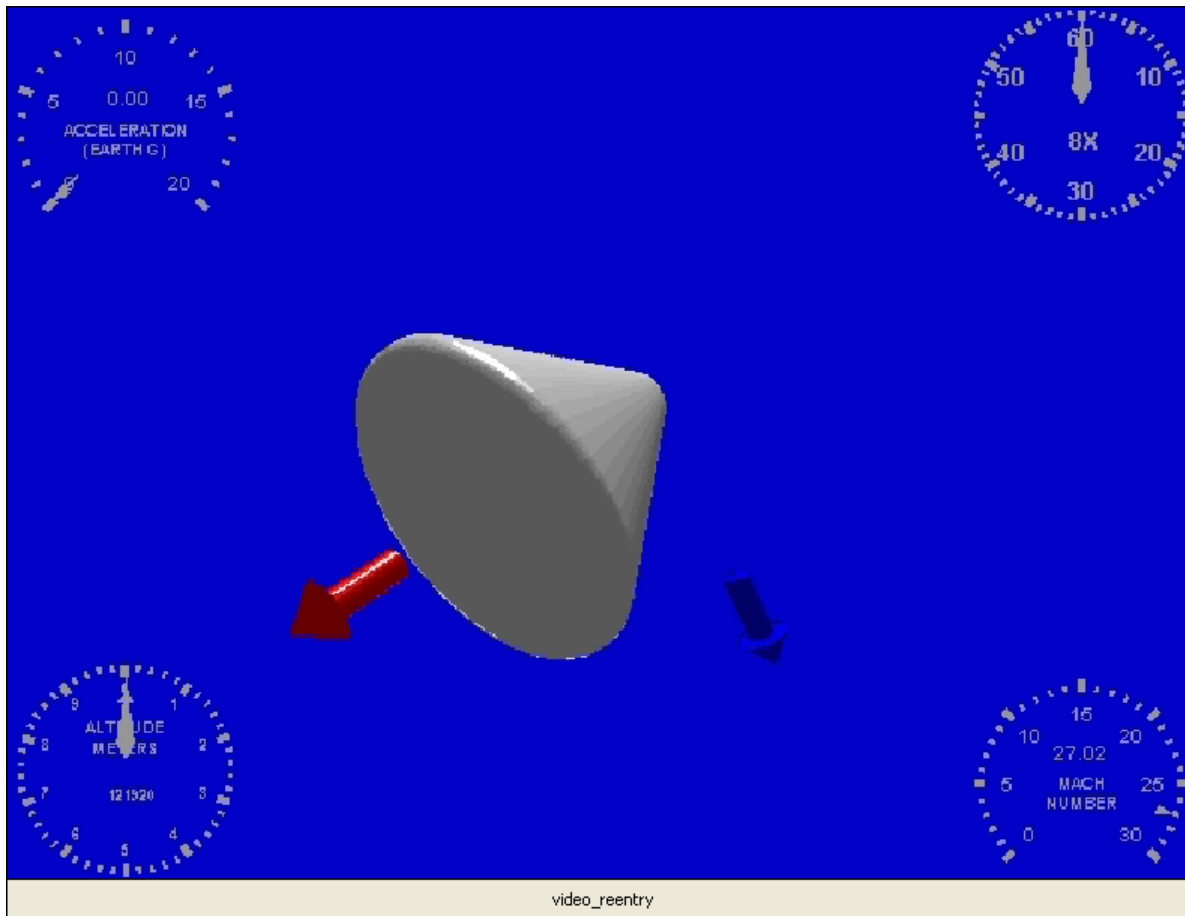


# RM Performance Summary

	Maximum Deceleration (Earth g's)	Maximum Heat Rate (W/m <sup>2</sup> )	Total Heat Load ( J/m <sup>2</sup> )
<b>Apollo CM</b>	6.9151	2.111X10 <sup>6</sup>	2.441X10 <sup>8</sup>
<b>Baseline RM</b>	7.5105	1.514 X10 <sup>6</sup>	1.809 X10 <sup>8</sup>
<b>Final Rev. RM</b>	7.0140	1.926 X10 <sup>6</sup>	2.251 X10 <sup>8</sup>



# RM Re-entry Video



# Reliability Calculations

- Determined using Quantitative Risk Assessment System (QRAS)
- Based on number of cycles or cumulative usage times for systems, components, and maneuvers
- Calculates probability of any failure without the assumption of critical failures
- Rendezvous and docking maneuvers are the source of lower reliability in PM and LAM

Design	Apollo	Baseline	Final Revision
RM	98.1%	98.6%	98.6%
PM	97.9%	96.7%	96.4%
LAM	97.2%	97.6%	97.1%
LDM	99.4%	97.7%	97.6%
CEV EDS	99.6%	98.7%	98.7%
LSAM EDS	N/A	98.7%	98.7%
System Total	92.5%	88.6%	87.8%



# NAFCOM

- Costing tool for space systems
- Primary drivers are mass and technology development
- Produces costing estimates for flight unit, design, development, and testing, and total project cost
- Accounts for manned and unmanned spacecrafts, launch vehicles, and probes

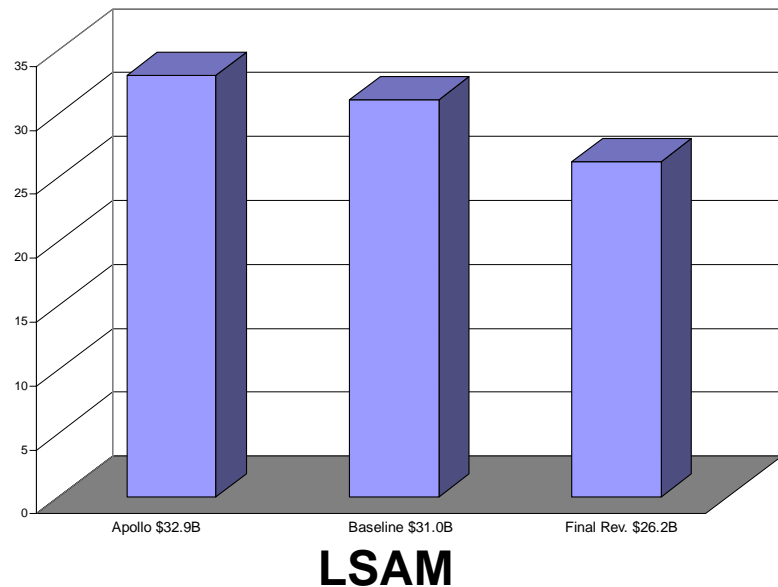
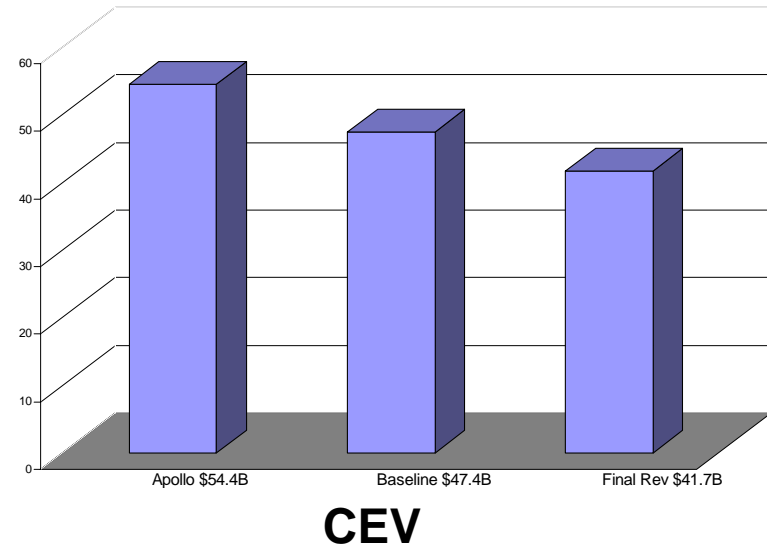


# Costing for CEV and LSAM

## Final Revision Cost

- CEV - \$41.7
- EDS - \$9.9
- LSAM - \$26.2
- Includes
  - Development Cost
  - 30 Flights

\*cost in billions of US  
2002 dollars



# TOPSIS

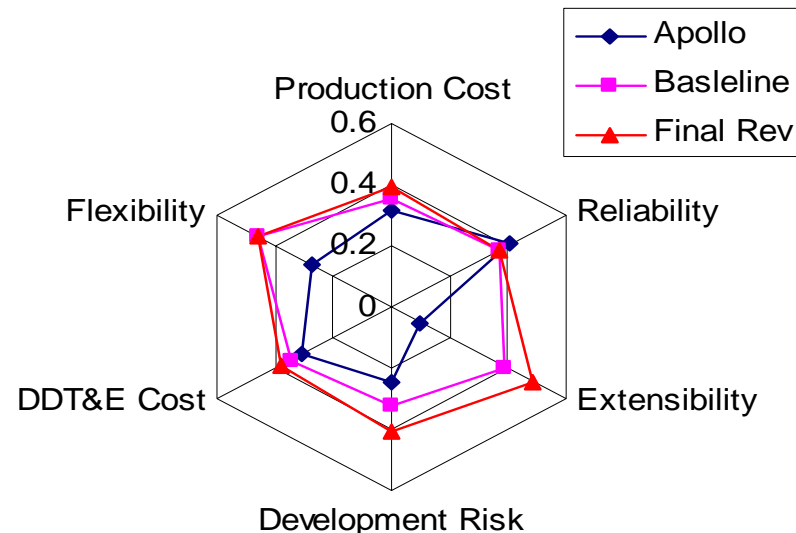
- Decision making tool which relies upon Analytical Hierarchy Process
- Ranks various alternative from 1 the worst to 9 the best and determines the overall best
- Allows less experience decision maker to make decisions on a more advanced level



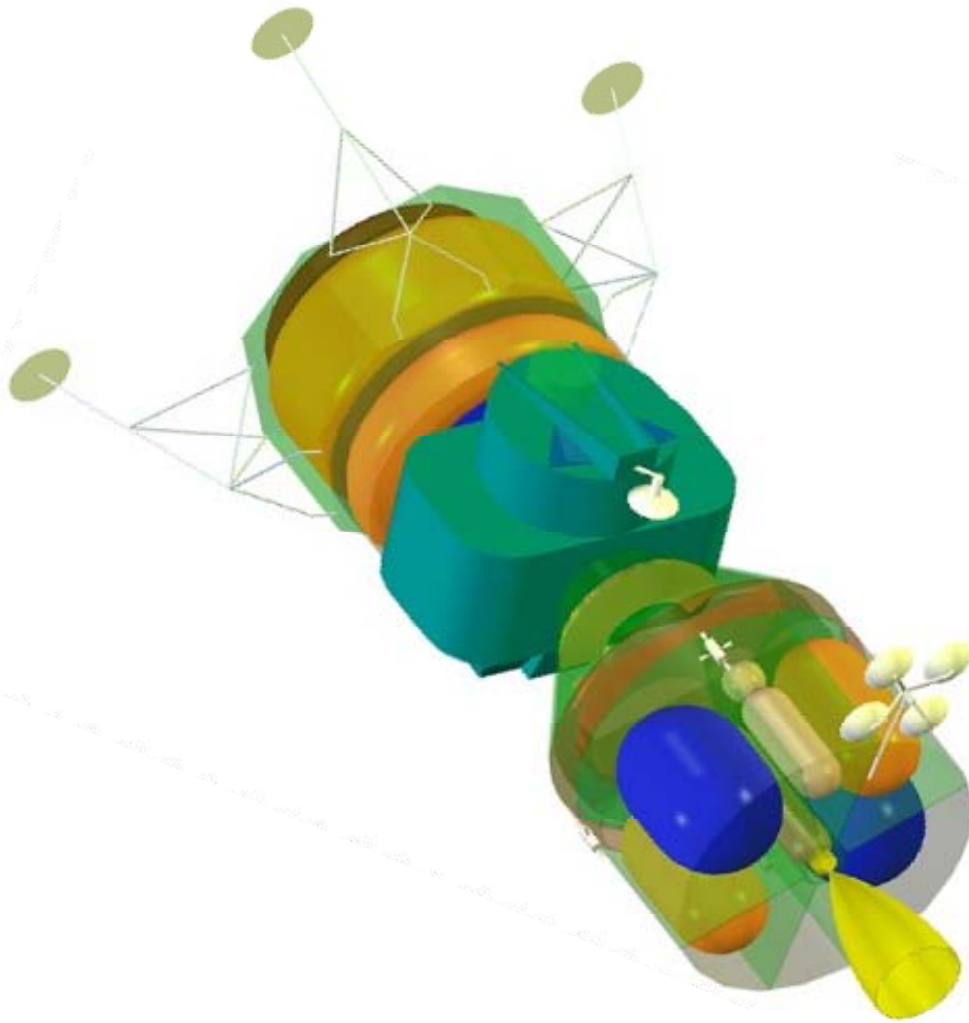
# Multi-Attribute Decision Making

- Requirements analysis produced six discriminating FOMs.
- AHP was used for pair-wise comparisons and weightings of the FOMs.
- Vehicle alternatives were developed from the combination of trade studies.
- TOPSIS was used to rank the alternatives using the FOMs and AHP weightings.
- One clear alternative ranked top with two different datum and it was shown that Apollo was not compatible with the new FOMs.

<b>Production Cost</b>	Cost of manufacturing all required element over the lifecycle of the program.
<b>Reliability</b>	Probability of a hardware failure, critical or otherwise.
<b>Extensibility</b>	Applicability and extensibility of technologies, systems, and operations of a lunar mission architecture to other potential exploration missions/destinations.
<b>Development Risk</b>	Applicability and extensibility of technologies, systems, and operations of a lunar mission architecture to other potential exploration missions/destinations.
<b>DDT&amp;E Cost</b>	Cost to design, develop, test, and evaluate all architecture systems to IOC.
<b>Flexibility</b>	Ability of an architecture to increase capabilities to meet evolving mission requirements.



# Final Revision

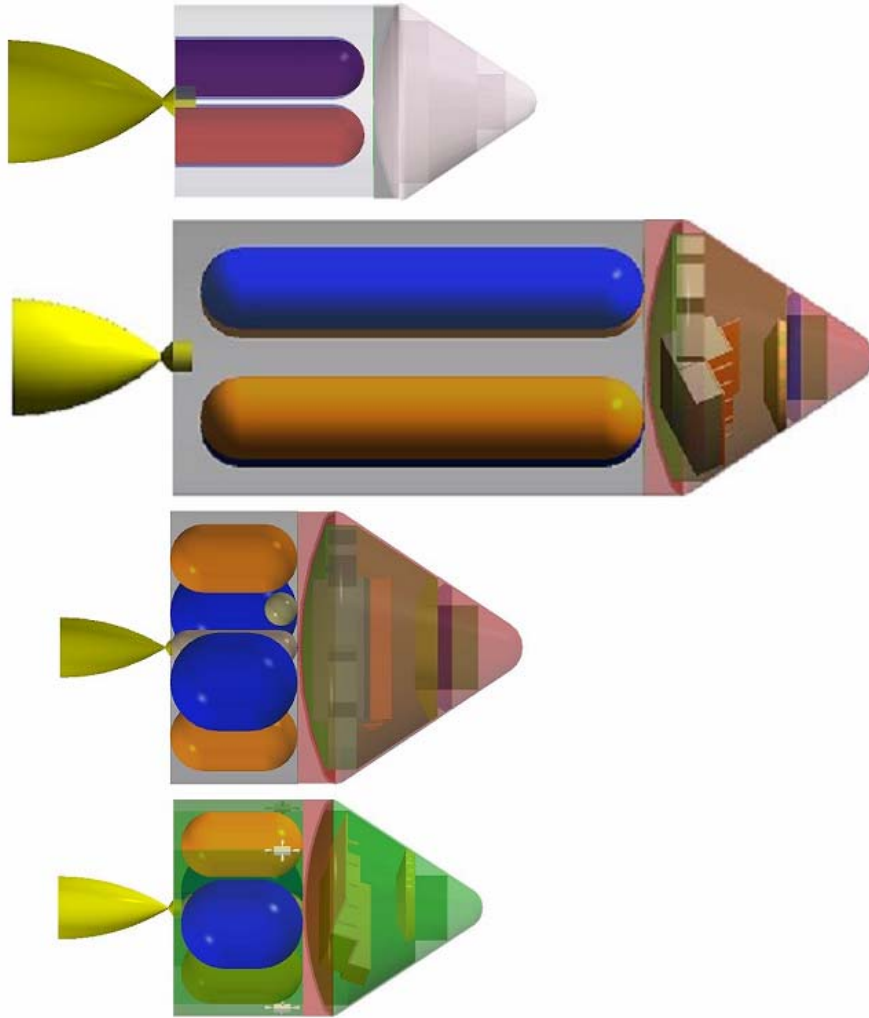


- Changed to LOX/LH2 RL-10B-2 Engines for LDM and LAM
- Toroidal tank configuration on LDM and LAM
- Ga-Ar body mounted solar arrays with Li-ion batteries on LSAM and CEV
- Primarily Aluminum structure
- Inflatable airlock
- Sized according to required volume per crew





# Comparison of Designs



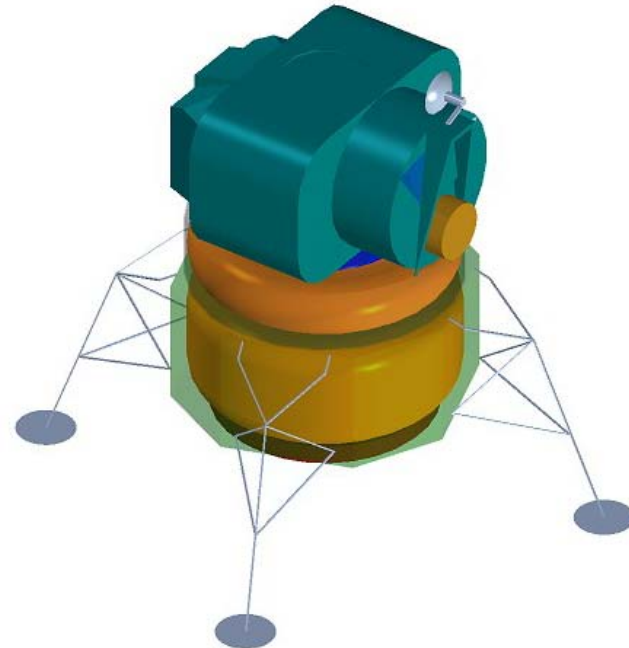
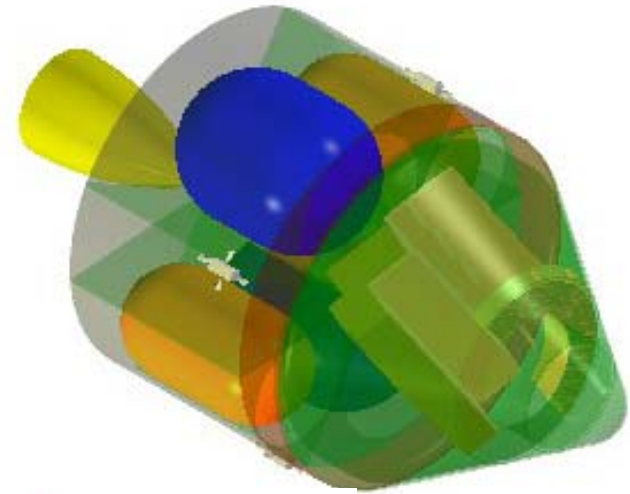
Design	Apollo	Apollo w/new RQs	Baseline	Final Revision
RM	5922	11171	9639	7405
PM	24721	44272	27248	20116
LAM	4795	13737	11748	8785
LDM	11642	27146	21028	12429
CEV EDS	119900	N/A	58765	48614
LSAM EDS	N/A	N/A	75803	52980

\*all masses in kg



# Summary

- Started from proven Apollo concept
- Adjusted for new requirements and mission objectives
- Added new technologies to decrease size and cost.



# Questions?

- We would like to thank
  - Dr. Alan W. Wilhite
  - Dr. Doug Stanley
  - Ben Raiszedah
  - NASA Langley
  - Georgia Institute of Technology
  - National Institute of Aerospace

